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A Study of a Multi-Level Bottom Trawl for Species Separation Using Direct Observation Techniques

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A Study of a Multi-Level Bottom Trawl for Species Separation Using Direct Observation Techniques

J Main and G I Sangster

Marine Laboratory Aberdeen

Introduction

It is generally believed that size selection during trawling is controlled by the cod-end mesh size, which allows small fish to escape from the net. Recent direct observations have shown firstly that many small roundfish succeed in escaping before entering the cod-end, for example through the meshes in the batings and extension piece, and secondly that, of those juvenile fish that do enter the cod-end, many are in fact capable of passing through the cod-end meshes, but are prevented from doing so by other fish (especially flatfish) masking these meshes (Main and Sangster, 1981a and Plate I). It has been

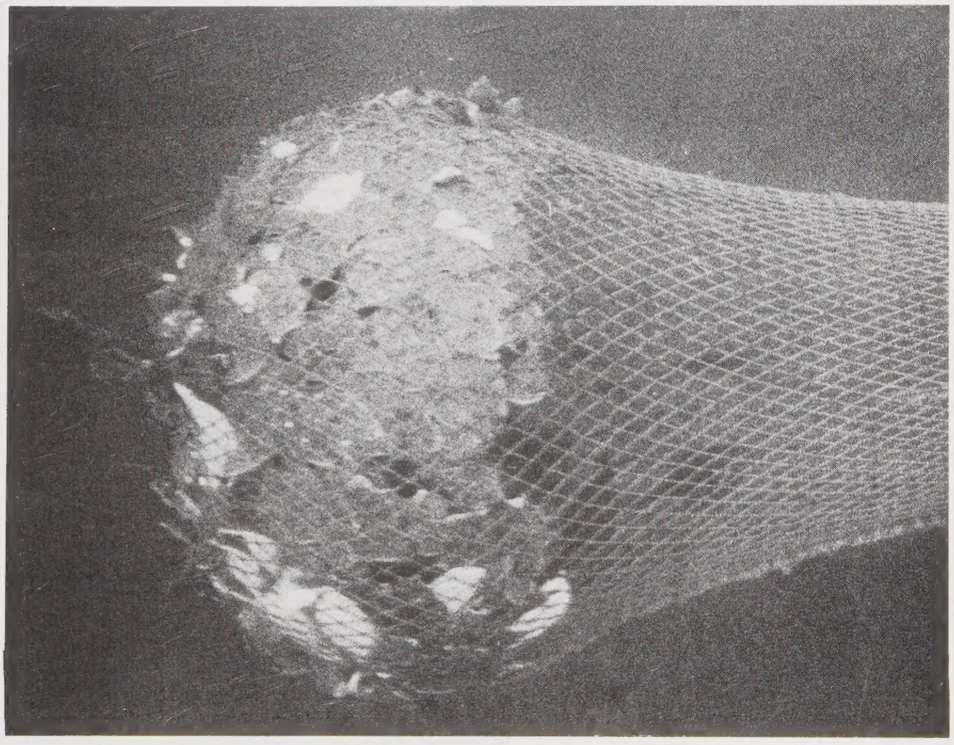

Plate I. Flatfish masking the meshes in the rear part of a cod-end.

suggested that similar masking accounts for the recent high discard rates of small and undersized roundfish in the North Sea reported by Jermyn and Robb (1981). Direct observation has also shown that long term damage to these young fish can be caused by descaling and abrasion in the cod-end and during escape through a mesh, but as yet this has not been fully investigated. While making direct observations of fish reactions to bottom trawls the authors have discovered another type of selectivity taking place in the mouth of the trawl. It is associated with the behavioural changes and responses of particular species of commercially important fish as their limit of swimming stamina is reached and they begin to drop back into the advancing net. For example, haddock when tiring rise high off the seabed before passing back over the footrope, whereas cod, skates and flatfish enter the net very close to

the seabed. Whiting and saithe, although swimming slightly higher off the bottom than the haddock during herding, enter the net at a level below the haddock, but above the flatfish (Main and Sangster, 1981a). Knowledge of this specific induced behaviour has already been used successfully for the separation of haddock and whiting during trawling for *Nephrops* using a two-level trawl with separate cod-ends (Main and Sangster, 1982). In view of this success, a three-level trawl (multi-level) was designed in collaboration with the net design team at the Marine Laboratory, Aberdeen. The present study investigates the possibility and practicability of separating at the mouth of the net haddock and whiting from cod, skates and flatfish, using one net rigged with two internal horizontal separating panels, with independent cod-ends.

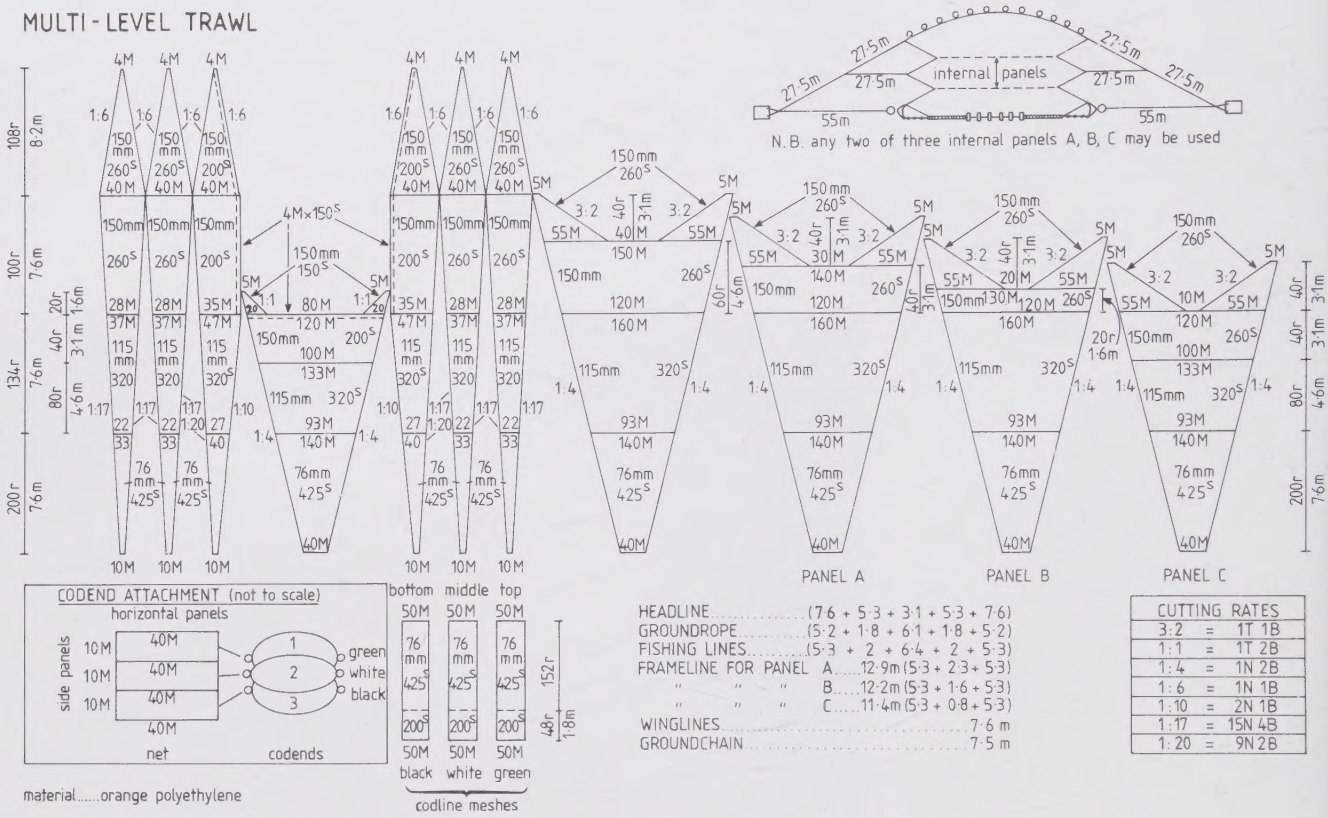

Figure 1. Net drawing of the multi-level trawl.

Materials and Methods

Experiments were conducted during the spring and autumn of 1981 on commercial fishing grounds around Northern Scotland, using the fisheries research vessel "Clupea" (32 m 600 hp). In a series of trawling tests two similar multi-level nets were used (Fig. 1) with different internal horizontal separator panel arrangements; these are termed nets A and B, (see Fig. 2). The higher panels in net A are stepped progressively forward from the fishing line, and in net B the two internal panels are rigged directly above the fishing line.

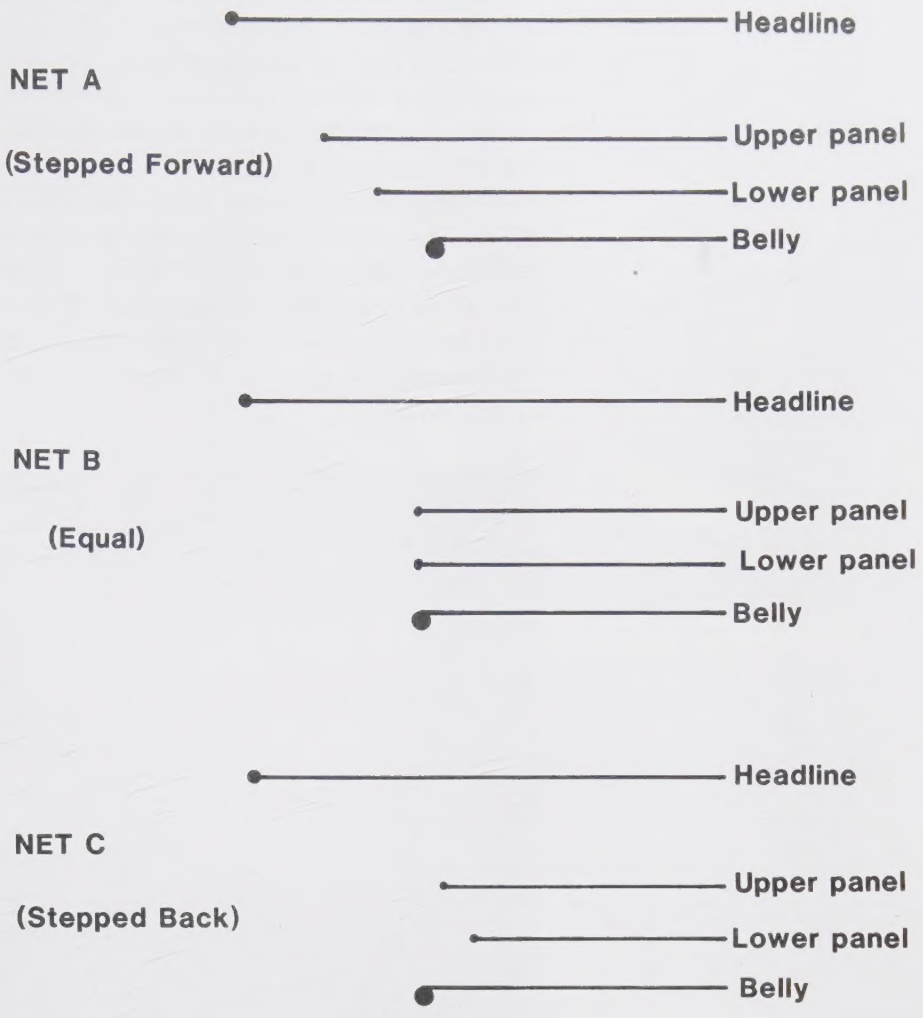

Figure 2. Line drawing showing the three variations of the separator panels.

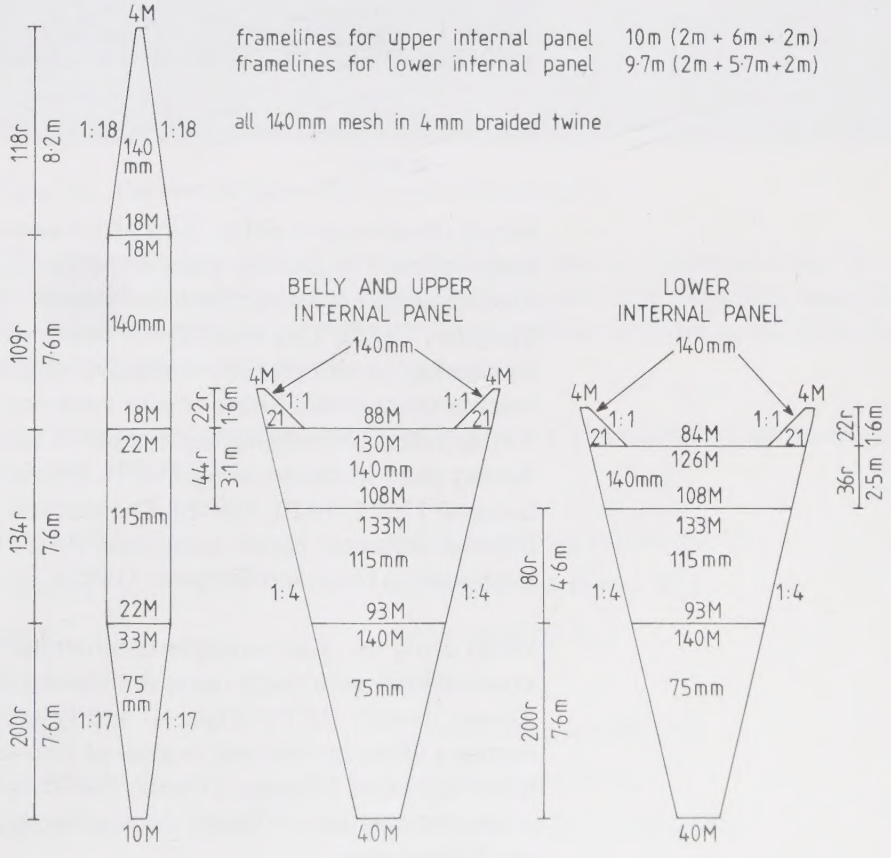

Figure 3. An additional design variation to the multi-level trawl uses these internal separator panels and side panels.

In a second series of experiments net C (a third version) uses the arrangement seen in Figure 2. The middle and lower side-panels are also constructed differently (Fig. 3) compared with nets A and B (Fig. 1). In net C the lower panel (Fig. 2) was stepped back 0.6 m from the belly fishing line and the upper panel (Fig. 2) was above and slightly behind the fishing line (net C, Fig. 2). The trawl boards were wooden, rectangular flat (2.7 m x 1.37 m) and their design specifications are as described in the FAO Fishing Manual (Anon., 1974). The duration of the trawl tows varied from one to two hours. Thirty-one hauls were carried out in daylight (depth range 60-120 m) and two were conducted in darkness (depth range 70-90 m). The towing speed at the ship was kept as near 1.54 m s^{-1} (3 knots) as possible using a calibrated speed log (flowmeter type giving ± 1% accuracy over a maximum range of 5.15 m s^{-1} or 10 knots).

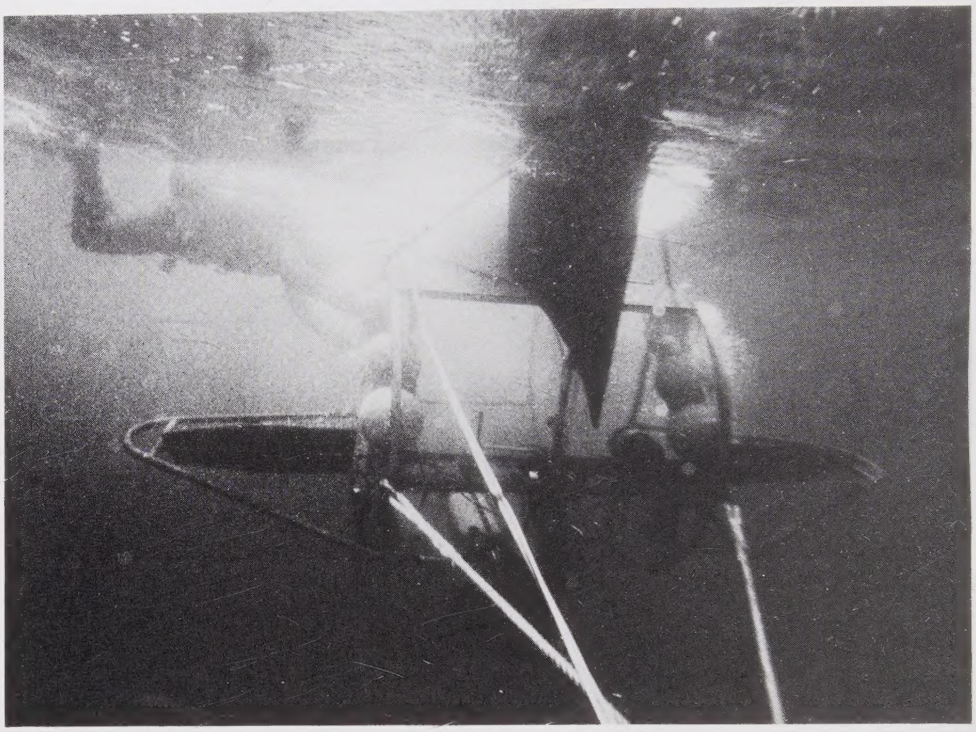

Plate II. The Towed Underwater Vehicle TUVII at the surface showing a diver about to enter.

Direct observations, video films and measurements of the whole gear were made initially in shallow water (20-30 m) by divers using the Marine Laboratory diver-operated towed underwater vehicle TUVII (see Plate II, Main and Sangster, 1978). This enabled the correct functioning of the whole gear to be checked *in situ* and any necessary adjustments to the internal panel heights to be made. These checks were made before each of the deep-water fishing tests. The various techniques of observing, filming and measuring fishing gears in action using TUVII, are described in detail by Main and Sangster (1978, 1979, 1981b). The method of controlling the levels of the internal separator panels using rope strops tied down at the panel quarters is explained in Main and Sangster (1982).

When using the gear in deeper commercial fishing grounds (70-90 m) direct observations were made using the Marine Laboratory Remote Controlled Towed Vehicle RCTV (Plate III and Priestley, in preparation). This vehicle carries a video camera and is steered into any position near the gear by spinning rotors (Magnus Effect). The dive, climb and lateral movement allow the scientist on board the towing ship to select and observe any part of the fishing gear.

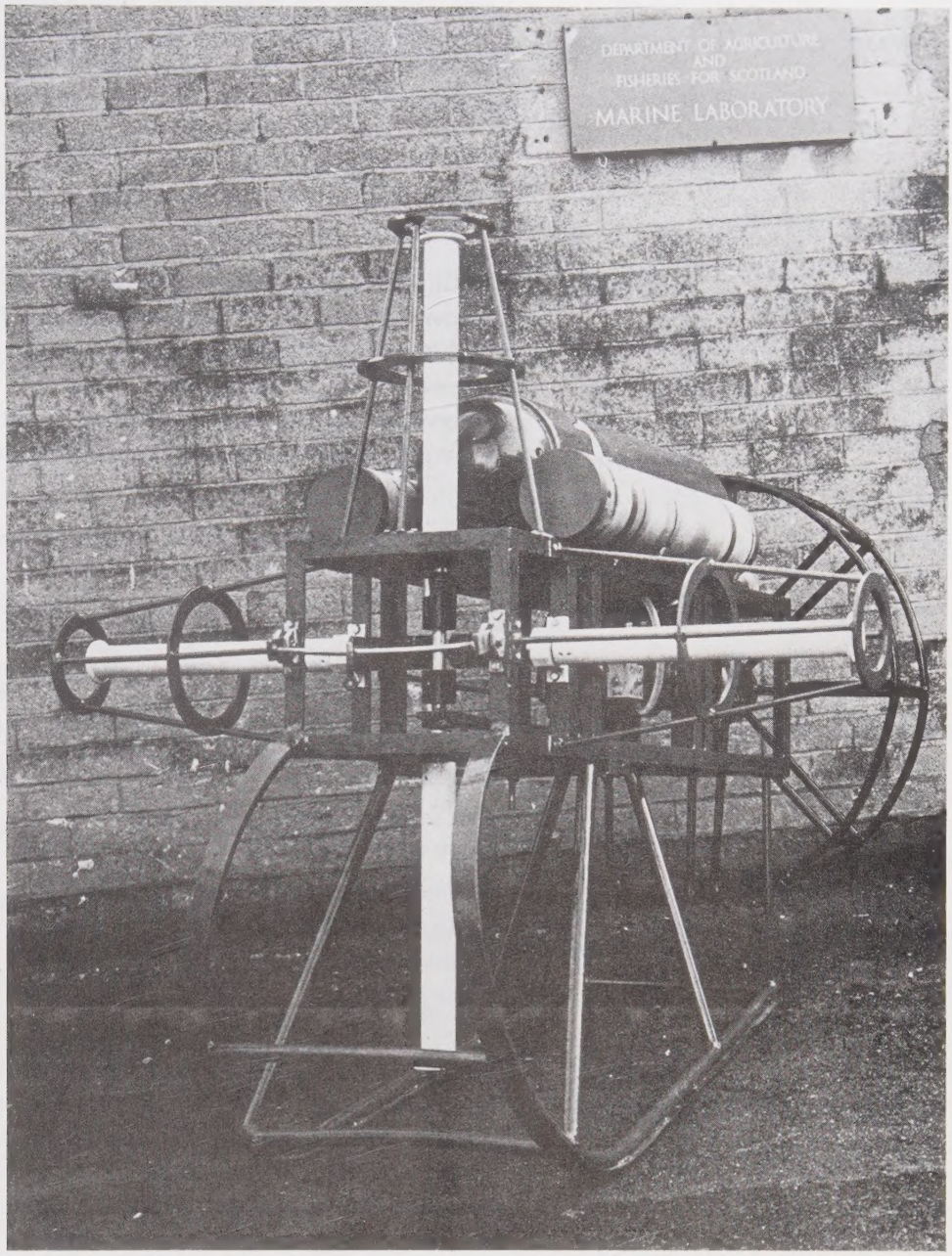

Plate III. The Remote Controlled Towed Vehicle RCTV.

The three separate compartments of the net lead to three cod-ends. On completion of each haul the contents of the cod-ends were kept separate and the fish measured and counted. Cod-end meshes were measured using the ICES mesh measuring gauge.

The fish species observed are listed below and the common names appear in the text and tables.

Haddock	—	*Melanogrammus aeglefinus* (L.)
Whiting	—	*Merlangius merlangus* (L.)
Cod	—	*Gadus morhua* (L.)
Skates	—	Rajidae
Plaice	—	*Pleuronectes platessa* (L.)
Common Dab	—	*Limanda limanda* (L.)
Lemon Sole	—	*Microstomus kitt* (Walbaum.)

Lesser Spotted Dogfish	—	*Scyliorhinus caniculus* (L.)
Spur Dogfish	—	*Squalus acanthias* L.
Grey Gurnard	—	*Eutrigla gurnardus* (L.)
Herring	—	*Clupea harengus* L.
Angler	—	*Lophius piscatorius* L.

Results

The dimensions of each version of the multi-level net were measured in shallow water while fished with 137 m (75 fathoms) of trawl warp between the ship and the otterboards.

Underwater visibility during these experiments was good and it was possible to identify individual fish species at a range of approximately 10 m.

Table I Measurements of Net A — Towing Speed 1.54 m s^{-1} (3 knots)

	No Strops	First Panel Tied Down with 0.75 m Strops	First Panel Tied Down with 0.45 m Strops
Trawl board spread	36.5 m	not measured	not measured
Wing end spread	12.2 m	11.6 m	11.6 m
Wing end height	3.3 m	3.4 m	3.3 m
First separator panel height above fishing line	1.2 m	0.75 m	0.45 m
Second separator panel height above fishing line	2.4 m	2.4 m	2.4 m
Headline height above seabed	4.9 m	4.8 m	4.8 m

Net A — Measurements and Catches

The net version A (Fig. 2) was fished with three different panel heights; these and the net measurements are shown in Table I. The net was measured initially without the internal panel levels being adjusted (ie no strops — see Table I column 1). The results of the catches from eight daylight trawl hauls (depth 65-90 m) without strops are shown in Table II. As high percentages of haddock were caught in the middle and lower cod-ends (37.5% and 40.9% respectively — Table II), the height of the lower separator panel was lowered and set at 0.75 m; the catches from the three resulting daylight hauls are shown in Table III. In a further attempt to minimise the quantities of haddock and whiting in the lower codend the height of the lower separator panel was again changed and set at 0.45 m above the belly panel. Table IV shows the catch results from three more daylight hauls with this setting. The poor separation results are explained by the following direct observations.

Direct observation of net A

Direct observations of net A (Fig. 2) were made using the Remote Controlled TV Vehicle (RCTV) on five two-hour daylight hauls at 70-90 m depth. These observation periods included all the internal panel height experiments described above. The observations showed that the net A arrangements with the fishing lines stepped progressively forward in advance of the bobbin groundline was not allowing species selection to take place at the mouth of the trawl. The previously mentioned reactions of the haddock and whiting when tired or exhausted (Main and Sangster, 1981a) were affected by the presence of the overhanging netting panels, and these typical reactions did not occur. Large numbers of both species were seen striking the lower panel from beneath and passing up through the meshes of both the lower and upper panels. When this occurred, both haddock and whiting were seen to

Table II Net A Catches from Eight Daylight Hauls (Depth 65-90 m), without Strops

The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	
Haddock	21.6 (2,418)	18-49	431	37.5 (4,200)	19-61	894	40.9 (4,580)	17-59	1,245	11,198
Whiting	41 (368)	17-51	63	40.5 (363)	19-49	73	18.5 (166)	14-51	58	897
Cod	0	-	-	3.4 (4)	32-53	0	96.6 (108)	38-70	5	112
Skates	0	-	-	0	-	-	100 (37)	34-49	-	37
Flatfish	0	-	-	1.5 (9)	29-34	0	98.5 (585)	17-39	398	594
Spotted Dogfish	0	-	-	2 (3)	63-75	-	98 (146)	59-75	-	149
Spur Dogfish	7 (121)	52-74	-	19.1 (331)	50-76	-	73.9 (1,279)	46-74	-	1,731
Gurnards	0	-	-	0	-	-	100 (35)	25-37	-	35

Table III Net A Catches from Three Daylight Hauls (Depth 60-144 m)

First separator fishing line set at 0.75 m above groundline. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under sized	Total Catch % (Number)	Size Range (cm)	Number of Under sized	
Haddock	11.6 (33)	18-47	4	67.4 (194)	21-48	119	21 (60)	16-33	34	287
Whiting	7.2 (10)	20-23	10	59.6 (85)	18-30	63	33.2 (47)	15-29	32	142
Cod	0	-	-	4.5 (2)	43-45	0	95.5 (42)	39-89	0	44
Skates	0	-	-	0	-	-	100 (10)	34-47	-	10
Flatfish	0	-	-	0	-	-	100 (47)	20-38	16	47
Spotted Dogfish	0	-	-	0	-	-	0	-	-	0
Spur Dogfish	0	-	-	0	-	-	0	-	-	0
Gurnards	0	-	-	0	-	-	100 (14)	25-37	-	14

Table IV Net A Catches from Three Daylight Hauls (Depth 60-70 m)

First separator panel fishing line set at 0.45 m above groundline. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersize fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	
Haddock	32.2 (95)	20-44	24	41.5 (123)	21-50	41	26.3 (78)	17-42	48	296
Whiting	24.8 (48)	24-34	20	34.8 (68)	19-37	18	40.4 (78)	18-35	60	194
Cod	0	-	-	8.2 (2)	32-46	0	91.8 (22)	34-46	0	24
Skates	0	-	-	0	-	-	0	-	-	0
Flatfish	0	-	-	0	-	-	100 (78)	18-29	57	78
Spotted Dogfish	0	-	-	0	-	-	0	-	-	0
Spur Dogfish	0	-	-	0	-	-	0	-	-	0
Gurnards	0	-	-	0	-	-	100 (14)	17-35	-	14

swim in fast erratic dashes and many passed through both internal panels and escaped through the square or top sheet of the net. Other groups of haddock were seen to rise up from the seabed between the wings, ahead of the net and escape over the headline (headline height 4.8 m – Table I). These escape reactions of the haddock have been noted on a number of occasions in similar sized trawls where separating panels were not present (Main and Sangster, 1981a).

Plate IV. Multi-level trawl (Net B version) viewed from the port side, showing both upper and lower separator panels rigged directly above the bobbin groundline.

Net B – Measurements and Catches

Table V shows three sets of measurements of version B (Fig. 2) of the trawl. Without strops, direct observations had shown the internal panels to be too high above the seabed for favourable species selection to occur (Plate IV). The lower and upper panels were therefore set at a height of 0.45 m and

1.2 m respectively above the groundline (see Table V, column 2 for net measurements) and the results of six two-hour trawl hauls are shown in Table VI. This version of net B gave an aggregate separation of approximately 80% of the haddock and whiting catches into the top and middle cod-ends and a high proportion of the cod catch (87%) into the lower cod-end. Flatfish, skates, angler and gurnards were nearly all caught in the lower cod-end. However, the haddock and whiting were being caught almost equally in the top and middle cod-ends (Table VI). In an attempt to allow more haddock to rise up into the top cod-end the upper separator panel only was adjusted to 0.90 m above the groundline (see Table V – column 3 for net dimensions) and the catch results obtained from five two-hour, daylight hauls using this setting are shown in Table VII. The results suggest that this particular rigging arrangement of net B was effective in separating species. Almost 80% of the haddock and 70% of the whiting catches were now being caught only in the top cod-end. The bottom cod-end caught all the flatfish, skates, angler, spotted dogfish and gurnards and also a high proportion of the cod (81%).

Table V Measurements of Net B

Speed 1.54 m s^{-1} (3 knots)

	No Strops	0.45 m and 0.75 m Strops between Fishing Line and Lower Panel and Upper Panel	45 cm Strops between Fishing Line and Both Panels
Trawl Board Spread	38 m	38 m	not measured
Wing End Spread	13.7 m	14.5 m	14.5 m
Wing End Height	4.3 m	4 m	4 m
First Panel Height above bobbins	1.5 m	0.45 m	0.45 m
Second Panel Height above bobbins	2.8 m	1.2 m	0.90 m
Headline Height	5.5 m	5 m	5 m

Table VI Net B Catches from Six Daylight Hauls (Depth 60-120 m)

First and second levels set at 0.45 m and 1.2 m respectively. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under sized	Total Catch % (Number)	Size Range (cm)	Number of Under sized	
Haddock	39.3 (2,056)	20-60	329	46.6 (2,437)	21-55	707	14.1 (738)	18-65	347	5,231
Whiting	44.6 (132)	16-46	16	40.8 (121)	20-46	16	14.6 (43)	14-47	20	296
Cod	0	-	-	13 (5)	35-53	0	87 (33)	32-60	0	38
Skates	0	-	-	0	-	-	100 (56)	26-52	-	56
Flatfish	0	-	-	0.3 (1)	30	0	99.7 (369)	18-57	46	370
Spotted Dogfish	0	-	-	5 (2)	57-75	-	95 (38)	56-62	-	40
Herring	59.1 (23)	23-30	-	40.9 (16)	21.27	-	0	-	-	39
Gurnards	0	-	-	0	-	-	100 (16)	18-41	-	16
Angler	0	-	-	0	-	-	100 (12)	35-46	-	12

Table VII Net B Catches from Five Daylight Hauls (Depth 68-75 m)

First and second levels set at 0.45 m and 0.90 m respectively. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Undersized	Total Catch % (Number)	Size Range (cm)	Number of Undersized	Total Catch % (Number)	Size Range (cm)	Number of Undersized	
Haddock	79.8 (7,127)	23-47	171	14.6 (1,304)	21-44	244	5.6 (500)	19-48	182	8,931
Whiting	70.7 (172)	25-38	19	15 (36)	22-35	3	14.3 (35)	24-35	3	243
Cod	0	-	-	19 (3)	40-49	0	81 (13)	33-61	0	16
Skates	0	-	-	0	-	-	100 (27)	30-45	-	27
Flatfish	0	-	-	0	-	-	100 (834)	14-39	597	834
Spotted Dogfish	0	-	-	0	-	-	100 (24)	49-73	-	24
Spur Dogfish	5.9 (4)	-	-	59.1 (40)	-	-	35 (23)	52-78	-	67
Gurnards	0	-	-	0	-	-	100 (55)	22-34	-	55
Angler	0	-	-	0	-	-	100 (22)	35-45	-	22

Table VIII Net B Catches from Two Hauls in Darkness (Depth 70-90 m)

First and second levels set at 0.45 and 0.90 m respectively. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Undersized	Total Catch % (Number)	Size Range (cm)	Number of Undersized	Total Catch % (Number)	Size Range (cm)	Number of Undersized	
Haddock	69.6 (5,562)	23-43	111	14.6 (1,166)	23-45	38	15.8 (1,262)	20-43	99	7,990
Whiting	46.4 (153)	29-42	0	22 (72)	27-49	0	31.6 (103)	25-39	3	328
Cod	0	-	-	50 (3)	47-49	0	50 (3)	37-39	0	6
Skates	0	-	-	0	-	-	100 (13)	31-47	-	13
Flatfish	0	-	-	3.8 (18)	19-28	11	96.2 (457)	12-31	317	475
Spur Dogfish	0	-	-	0	-	-	100 (4)	35-49	-	4
Gurnards	0	-	-	0	-	-	100 (4)	23-27	-	4

This latter adaptation of net B was then fished during darkness (no moon, depth 70-75 m, during October between 2000 and 2300 hours) and the results of the catches from two one-hour hauls are shown in Table VIII. The results suggest that when this version of the trawl is fished in darkness, haddock, skates, flatfish and gurnards show a similar separation to that shown in daylight (Table VII), although in darkness (10%) more haddock were caught in the lower cod-end. There is in both daylight and dark hauls a general trend for the greatest proportion of haddock to be caught in the top cod-end with these panel settings of Table VII and VIII. During darkness whiting catches were fairly evenly divided in the three cod-ends. No definite conclusion was drawn about the few cod that were caught except that the greatest proportion of this species is consistently caught in the lower level of the net in both daylight and dark (Table VII and VIII).

Direct observations of net B

Direct observations of net B (Fig. 2) were made on seven two-hour daylight hauls at 65-85 m depth and included both the rigging variations described in Table V, columns two and three.

The typical behaviour of the whiting when entering a bottom trawl without separating panels, as described by Main and Sangster (1981a), was not evident

when this species was seen entering the multi-level trawl. Whiting reacted to the presence of the lower panel fishing line. After turning towards the net some swam downwards into the lowest level and others swam into the middle and top levels. This behaviour was reflected in the catches (Tables VI and VII). Most haddock, however, repeatedly rose high off the seabed immediately in front of the bobbins and as far ahead as the wing ends and passed back into the top level of the net. Once again, during daylight, many haddock escaped over the 5 m headline from positions estimated to be as far forward as the wing ends. Flatfish, skates and spotted dogfish consistently entered only the lowest level.

Table IX Measurements of Net C

Towing Speed at 1.54 m s^{-1} (3 knots)

	No Strops
Trawl board spread	44 m
Wing end spread	13.2 m
Wing end height	3.3 m
First separator panel height above bobbins	0.55 m
Second separator panel height above bobbins	1.45 m
Headline height	4.6 m

Net C – Measurements and Catches

In an attempt to guide a higher proportion of the whiting into the middle cod-end the lower internal panel was rigged slightly behind the bobbin groundline (Net C, Fig. 2), but was maintained at the same lower panel height of net B (ie 0.45 m). Table IX shows the dimensions of this version of the trawl measured in shallow water. The distance of the lower panel behind the belly panel fishing line was estimated at approximately 1.5 m, at a towing speed of 1.5 m s^{-1}. Net C also uses narrower middle and lower side panels (Fig. 3), resulting in this carefully designed version being fished in deep-water without requiring adjustments to the internal panel heights. Table X shows the results of the catches from six two-hour daylight hauls using net C. The greatest proportion of haddock (78.1%) was again caught in the top cod-end and the numbers of haddock in the bottom cod-end were down by almost half compared with the haddock catches in the bottom cod-end of net B (Table VII). The total catches of whiting were low (only 62 individuals – Table X), but the indications were that, in net C, these fish were almost totally eliminated from the bottom cod-end and increased in the middle one. Cod, skates, flatfish and spotted dogfish were caught mostly in the bottom cod-end.

Direct observations of net C

Direct observations recorded on video tape were made in daylight on all the tows using net C with the stepped back panel arrangements. It was repeatedly seen that most haddock (more than 75%) rose off the sea bed, passed above the upper panel and entered the top level and, as in previous experiments, a large proportion of those well ahead of the groundline succeeded in escaping over the headline. Skates, flatfish and spotted dogfish were seen swimming ahead of the footrope, dropping back and entering the bottom level. However, it was unfortunate that no definite observations were made of whiting reactions to the stepped back internal panels because it was difficult to discriminate between the few whiting and the large numbers of haddock mixed together in the path of the net.

Table X Net C Catches from Six Daylight Hauls (Depth 66-70 m)

First and second levels fishing at 0.55 m and 1.45 m respectively above the bobbins. The percentage of the total catch and the equivalent numbers are given for each species as well as the size range and percentage of undersized fish in the three levels

Species	Top Level			Middle Level			Bottom Level			Total Catch of Each Species (Numbers)
	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	Total Catch % (Number)	Size Range (cm)	Number of Under sized	Total Catch % (Number)	Size Range (cm)	Number of Under-sized	
Haddock	79.1 (6,496)	25-45	162	17.4 (1,429)	20-44	160	3.5 (288)	20-42	10	8,213
Whiting	52.8 (33)	30-36	0	42.6 (26)	29-35	0	4.6 (3)	29-34	0	62
Cod	0	-	-	6 (2)	51-53	0	94 (34)	32-40	0	36
Skates	0	-	-	0	-	-	100 (31)	28-45	-	31
Flatfish	0	-	-	0.8 (3)	21-24	3	99.2 (378)	17-33	250	381
Spotted Dogfish	0	-	-	12.5 (6)	59-65	-	87.5 (40)	53-75	-	46
Spur Dogfish	28.7 (92)	45-75	-	44.3 (143)	42-76	-	27 (88)	58-78	-	323

Size Selectivity by Cod-end Mesh of Nets A, B and C

The range and mean of stretched mesh sizes of each cod-end used in these experiments are shown in Table XI. Fifty meshes were measured from each cod-end. Minimum legal landing sizes in Scotland of 27 cm for haddock and whiting and 30 cm for cod were used as the basis for calculating the numbers of undersized fish present in each cod-end. The category "flatfish" represents plaice, common dab and lemon sole. A 25 cm minimum length figure was used in presenting the undersized flatfish results. The proportions of undersized fish caught in each net are shown in Tables II, III, IV, VI, VII, VIII and X and the catches of commercially important species (haddock, whiting, cod and flatfish) are summarised in Table XII. Without knowing the total number of undersized fish passing through the net we can only say that large numbers of juvenile haddock were retained in all versions of the nets tested and that small flatfish were retained in large numbers in only the bottom cod-end of all three nets.

Table XI Cod-end Mesh Sizes from All Versions of the Multi-Level Trawl

50 random meshes measured from each cod-end

Type of Trawl	Top Cod-end	Middle Cod-end	Bottom Cod-end
Net A (stepped forward version)	mean 74 mm range 72-77 mm	mean 74 mm range 71-76 mm	mean 75 mm range 72-78 mm
Net B (equal version)	mean 74 mm range 69-76 mm	mean 74 mm range 72-77 mm	mean 73 mm range 72-76 mm
Net C (stepped back version)	mean 73 mm range 70-76 mm	mean 74 mm range 72-76 mm	mean 74 mm range 71-76 mm

Discussion

These experiments showed the value of direct observations of the detailed behaviour of the fish and the performance of the net, combined with fishing the net in the normal way, in order to test the multi-level trawl.

Comparison of the Species Separation in the Multi-Level Trawls

Comparing the catches of all three nets shows immediately that separation of the species was effected by the details of positioning of the panels. The stepped-forward version (Net A, Fig. 2) gave the least separation of haddock and whiting from cod, skates and flatfish, because large numbers of haddock and whiting were caught in all three cod-ends. Net B (Fig. 2 — equal panels)

Table XII Summary of the Catches of Undersized Haddock, Whiting, Cod and Flatfish in Each Cod-end

Table	Species	Top	Middle	Bottom
II	Haddock	431	894	1,245
III		4	119	34
IV		24	41	48
VI		329	707	347
VII		171	244	182
VIII		111	38	99
X		162	160	10
II	Whiting	63	73	58
III		10	63	32
IV		20	18	60
VI		16	16	20
VII		9	3	3
VIII		0	0	3
X		0	0	0
II	Cod	0	0	5
III		0	0	0
IV		0	0	0
VI		0	0	0
VII		0	0	0
VIII		0	0	0
X		0	0	0
II	Flatfish	0	0	398
III		0	0	16
IV		0	0	57
VI		0	0	46
VII		0	0	597
VIII		0	11	317
X		0	0	250

caught mostly haddock (79.8%) in the top cod-end when the upper and lower panel heights were set at 0.45 m and 0.90 m respectively (Table VII), but most of the whiting catch (70.7%) was also in the top cod-end using these settings. Fishing this version of net B at night (Table VIII) resulted in most haddock being caught in the top cod-end and the skates, flatfish, dogfish and gurnards in the bottom one. Whiting catches were spread over the three cod-ends. However, when daylight and dark fishing of net B were compared, most haddock (79.8% and 69.6% – see Tables VII and VIII respectively) were caught in the top cod-end. We know from many direct observations that in daylight haddock swim in front of a trawl close to the bottom and rise off the sea bed when tired or exhausted and that, given good underwater visibility, their reactions to a fishing gear are governed to a considerable extent by vision (Main and Sangster, 1981a). So in daylight in clear water we would expect most haddock to be caught in the top cod-end. However, at night fish vision is affected by the reduction in ambient light and visual range is reduced (Anthony, 1981). Will the fish's reaction distance to a trawl component also be reduced during darkness? In darkness, netting panels moving through the sea can be made wholly or partially visible if bioluminescent planktons are present in the water (Main and Sangster, 1981a). A fish can utilise vision and hearing to identify an approaching object or sound; which is used will depend on the range of the source, the water turbidity and the prevailing light level, but hearing can never give as much directional information as a visual fix (Hemmings, 1967).

The haddock's rising behaviour may differ between day and night or the distribution of haddock in the water column may change from day to night due to local conditions. During the night fishing experiments the echosounder showed that all the fish traces were close to the seabed, and the haddock results in Table VIII suggest that if the haddock were part of these traces a high proportion (69.6%) did rise up into the top level of net B. No pattern emerges from the whiting catches during darkness. However, without evidence from direct observation of fish reactions to a fishing gear at night, we cannot assume from what comes up in the cod-end that fish behave and react similarly during day and night.

In daylight, the catches from net C (Fig. 2 – stepped back) gave the most practical results for separating haddock from cod, skates and flatfish, but the whiting catch was still divided equally between the top and middle cod-ends (Table X).

The Practicability of the Multi-Level Trawl

These experiments show that it is possible to control the fate of the majority of both haddock and groundfish when trawling, but to achieve the same consistently for whiting using this fishing method may be impossible or impractical. Tables VI and VII show that only relatively small adjustments to the heights of the separating panels greatly alter the catches of haddock and whiting in the top and middle cod-ends. It is, however, important to have these heights stabilised by rope strops at a level that suits the behaviour of the fish. Failure to do this will almost certainly result in the separating panels changing height during trawling, and a controlled separation of the species into the three cod-ends will not occur. If the industry were to try this method of fishing as it stands and attempt to separate species during trawling by blind adjustment to the panel heights and positions, it is highly unlikely they would succeed. Direct observation allows careful setting of the panel heights, but a carefully designed and accurately tailored net is clearly needed if the same practical separation of fish species is to be achieved commercially.

The success previously achieved in separating more than 95% of haddock and whiting catches from *Nephrops* and groundfish using a trawl (Boris 520 Fish/Prawn trawl) rigged with a single separator panel (Main and Sangster, 1982) suggests that this may be the answer to this problem. However, some experimentation with the setting of the separator panel height by strop adjustments would be necessary to obtain the best results. During another series of experiments with this two level fish/prawn trawl on board a commercial side trawler ("Aries", BCK 126, August 1981), approximately 90% separation of haddock and saithe from groundfish resulted from six two-hour hauls in daylight (Main and Sangster – unpublished results). The same sort of result is obtained if we combine the top and middle catches of net C shown in Table X (see Table XIII). Furthermore, practical separation is achieved by similarly combining the middle and upper level catches of net B (Table VII) as shown in Table XIV. Tables XIII and XIV show that the majority of haddock and whiting can be separated from groundfish, using either the stepped back or "equal" panels version of the net, but that the stepped back position of the separator panel fishing line will allow more whiting to enter the upper level (Table XIII).

The cod separation percentages (Tables XIII and XIV) were obtained from a relatively small number of individuals in comparison with the other species caught. However they show that most cod are consistently caught in the bottom cod-end. More recent results from two types of two level trawls (clean and bobbin groundgear) have shown that cod (more than 90%) are consistently caught in the bottom cod-end of both nets in daylight on most types of seabeds (Main and Sangster, 1982, and unpublished results).

Table XIII Aggregate results from Table X (Net C) of the Top and Middle Levels Shown as Percentages against the Bottom Level Figure

Species	Aggregate Top and Middle Levels	Number of Undersized	Bottom Level	Number of Undersized	Total Catch of Each Species (Numbers)
Haddock	96.5%	322	3.5%	10	8,213
Whiting	95.4%	0	4.6%	0	62
Cod	6%	0	94%	0	36
Skates	0	-	100%	-	31
Flatfish	0.8%	3	99.2%	250	381

Table XIV Aggregate Results from Table VII (Net B) of the Top and Middle Levels Shown as Percentages against the Bottom Level Figure

Species	Aggregate Top and Middle Levels	Number of Undersized	Bottom Level	Number of Undersized	Total Catch of Each Species (Numbers)
Haddock	94.4%	415	5.6%	182	8,931
Whiting	85.7%	12	14.3%	3	243
Cod	22%	0	78%	0	16
Skates	0	-	100%	-	27
Flatfish	0	0	100%	597	834

It could be concluded that a two-level trawl using a single separator panel is easier to set and is as good as a three-level trawl. The use of this type of trawling gear could lead to a better management of the fish stocks, by allowing species selection to take place in each cod-end depending on the mesh size.

Some Benefits from Multi-Level Trawl Fishing

There are advantages in using multi-level gear. The firm condition and appearance of the fish caught in the top and middle cod-ends are superior to those of fish retained in the bottom cod-end which have been damaged among the weeds, stones and crustaceans (Main and Sangster, 1982). These better quality fish from the top cod-end will be more acceptable to the buyer. The separation of species into three cod-ends will reduce the time spent on deck sorting out the catch. If the belly of the net is damaged or torn during a tow, fish of certain species (for example, haddock, whiting and saithe) will continue to be held in the top and middle levels. Flatfish are almost all caught in the bottom cod-end of the multi-level trawl; therefore masking of the cod-end meshes in the top and middle levels by these species will not occur. Small or juvenile fish reaching the upper cod-ends should have a better chance of escape. This would reduce the dumping of small and unwanted fish at sea and also improve the conservation of many commercially important fish stocks. Finally, each cod-end of the multi-level net can have a different mesh size to catch only the larger marketable fish, depending on consumer demand and stock management requirements.

The Importance of Knowing how Certain Fish Behave and React to Fishing Gears

We are beginning to realise that fish behave and react differently in the vicinity of the trawl (Main and Sangster, 1981a) and are not passively sieved out of the water column by an approaching net. For example, from Table X, without the prior knowledge gained from many direct observations, it could be wrongly assumed that approximately 80% of the haddock caught were swimming between 1.45 m (upper panel height) and 4.6 m (headline height) above the seabed when they were overtaken by the net. In daylight haddock in fact swim very close to the seabed (less than 1 m) during herding and

only rise when tired or exhausted (Hemmings, 1973; Main and Sangster, 1981a). It is this rising behaviour of the haddock which has the greatest influence in the separation of this species into each level of the trawl. Haddock are capable of escaping high over the headline of trawls from positions within the net mouth. However, the stepped forward version of the multi-level trawl induced another form of behaviour of haddock and whiting and a panic-like reaction accounted for the results (Tables II, III and IV). In these current experiments, cod were mostly caught in the bottom cod-end in both two-level and multi-level trawls as discussed, but small cod have been observed escaping under the bobbin spacers of a bottom trawl (Main and Sangster, 1981a). The cod behaviour of swimming very close to the seabed during herding and staying near the bottom when entering the net (Main and Sangster, 1981a) does tend to confirm these results. It appears, therefore, that accurate knowledge of fish behaviour and their reaction to the components of trawls is vitally important when designing fishing nets.

Summary

A series of three-level bottom trawls rigged with horizontal separating panels terminating in independent cod-ends was used in fishing trials in an attempt to separate commercially important fish at the mouth of the net according to their specific behaviour. In shallow water (25-30 m), divers using an underwater towed vehicle measured observed, and where necessary recorded, how adjustments to the nets should be made to allow the most favourable separation of each species prior to fishing in deep water. A remotely controlled television system enabled further direct observations of the working of each type of net to be made on commercial fishing grounds (70-90 m). Trawling was conducted by both day and night. Results showed that the majority of haddock consistently rose up from the seabed into the top level but many escaped over the 5 m headline. Whiting catches varied in the three cod-ends and may depend on the height setting and position of the first separator panel. Cod, flatfish, skates, angler, gurnards and spotted dogfish were caught almost solely in the bottom cod-end. Catches of haddock in the top cod-end of the net were similar during both day and night fishing, whereas whiting catches varied and definite conclusions were not drawn from these day/night results. The quality and condition of the fish caught in the top and middle cod-ends were far superior to those of fish caught in the bottom cod-end. The use of this type of fishing net will

(a) reduce the time spent on deck sorting out the catch; and

(b) allow fishing to continue in the top and middle levels if the belly is damaged or torn during a tow.

The need for a carefully designed and accurately tailored net to eliminate fine adjustment to the inner panel's heights to produce the most favourable species separation will be needed if this type of gear is to be at all acceptable for commercial fishing.

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